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EVALUATION OF TITANIUM DIBORIDE GUN TUBE COATINGS

ARTHUR J. BRACUTI
LOUIS A. BOTTEI

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U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
LARGE CALIBER WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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Samples of AISI 4140 and AISI 4130 steel were coated with the intermetallic compound titanium diboride (TiB_2) by means of a relatively low temperature electrodeposition process which does not harm the steel substrate. The erosion resistance of these samples was evaluated at various pressure levels in the U.S. Army Armament Munitions and Chemical Command vented closed bomb test fixture using laboratory prepared M30 propelling charges. The coated samples apparently eroded faster than steel. The effects of the TiB_2-steel interface

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20. ABSTRACT (cont)

dominated the data to such an extent that no legitimate comparison between steel and TiB_2 could be made.

INTRODUCTION

This study chronicles a continuing effort by this laboratory to evaluate the effectiveness of new materials as potential wear resistant gun barrel coatings. Materials that have been investigated previously include a combination of tantalum (ref 1) and refractory alloys CM500L (low temperature tungsten/carbon alloy), CM500 (tungsten/carbon alloy), and 98% tantalum/2% tungsten alloy (ref 2).

Titanium diboride (TiB_2), a very hard, high melting (3173 K), ceramic-like intermetallic compound, was not considered previously for gun barrel coatings because the available preparatory methods required high temperatures which would be detrimental to gun steel substrates. United Technologies, however, has recently developed a low temperature electrodeposition process (ref 3) which would not adversely affect the gun steel substrate yet would produce uniform reproducible adherent coatings. As a result, United Technologies Research Center, East Hartford, Connecticut supplied this laboratory with TiB_2 coated AISI 4140 and 4130 steel inserts which were tested in the ARDC vented closed bomb (erosion test device).

PROCEDURE

Electroplating

Both AISI 4130 and AISI 4140 sleeves were coated with TiB_2 by means of fused salt electrodeposition. This method, developed and patented by United Technologies (ref 3), employs an electrolyte composed of a molten eutectic mixture (m.p. 751 K) of potassium fluoride (KF), lithium fluoride (LIF), and sodium fluoride (NAF) in the molar ratios of 3.3:3.7:1, respectively. The sample to be coated serves as the cathode, while the anode which supplies the boron and titanium to the electrolyte is constructed of one part boron to three parts titanium (50 g B:150 g Ti per 1000 g molten electrolyte).

Electrochemical reactions that can occur at the cathode are

$$BF_4^- + 3e \qquad B + 4F^- \tag{1}$$

$$TiF_6^{-3} + 3e \qquad Ti + 6F^- \tag{2}$$

$$Na^+ + e \qquad Na \tag{3}$$

$$K^+ + e \qquad K \tag{4}$$

$$Li^+ + e \qquad Li \tag{5}$$

Since the reduction of the alkali ions (shown in reactions 3,4, and 5) require higher cell voltages than are required for the reduction of BF_4^- or TiF_6^{-3} (reactions 1 and 2), alkali metal contamination is avouded by employing proper cell voltage. The boron and titanium produced in reactions 1 and 2 react to form TiB_2 on the surface of the cathode

$$Ti + 2B \qquad TiB_2 \tag{6}$$

The oxidation reactions at the anode are

$$B + 4F^- \qquad BF_4^- + 3e \tag{7}$$

$$Ti + 6F^- \qquad TiF_6^{-3} + 3e \tag{8}$$

The BF_4^- is also involved in a competing equilibrium

$$BF_4^- \qquad BF_3 + F^- \tag{9}$$

in which the gaseous BF_3 at 839 K has a molar pressure high enough to leave the melt. To compensate for this loss, gaseous BF_3 is supplied to the system.

Erosion Testing

All erosion data were obtained with a 200-cm^3 closed bomb modified to accept a gun barrel (36 in. long) and a metal erosion sleeve (ref 4). This modified closed bomb, referred to as the erosion tester, is shown in figure 1. For this investigation, AISI 4340 steel sleeves, TiB_2 coated AISI 4130 sleeves, and TIB_2 coated AISI 4140 steel sleeves were used. Each sleeve was machined to have an outer diameter of 2.70 cm, an inner diameter of 0.95 cm, and a length of 2.06 cm. To control pressure, a 0.0056 cm stainless steel blow-out disc was placed between the barrel and the erosion sleeve. Pressure-versus-time measurements were obtained with a Nicolet digital oscilloscope connected to a pressure transducer positioned inside the chamber. In addition, the barrel was filled with water and the muzzle was sealed with a rubber stopper to ensure the proper peak pressure. Burn time was defined as the time interval between 5% maximum pressure and maximum pressure.

For two TiB_2 coated AISI 4130 and two TiB_2 coated AISI 4140 samples, the following test procedure was used: Each sleeve was weighed, fired three times, cleaned, and reweighed. This was repeated three times, and the average mass loss after nine shots was used as a measure of erosion. This procedure was used in the 150 MPa, 180 MPa, and 220 MPa pressure regions. For one sample, each of TiB_2-coated AISI 4130 and AISI 4140 steel, single shot measurements were made in the 150-MPa range in which the average erosion value was reported for ten shots.

Single shot erosion measurements were made on uncoated samples of AISI 4340 steel in the pressure ranges of 100 MPa, 150 MPa, 180 MPa, 220 MPa, and 260 MPa.

Internal ballistics were controlled selectively by adjusting the blow out discs and the M30 propelling charge weights to 30 g, 40 g, 50 g, and 60 g, which yielded peak pressures in the ranges of 100 MPa, 180 MPa, 220 MPa, and 260 MPa, respectively. Since the same propellant (M30 RD69531) was used throughout this investigation, flame temperature was a constant, while burn times and peak pressures were measured charge-mass dependent parameters. The composition and the physico-chemico properties, derived by the Blake code, of M30 propellant (ref 5) are listed in table 1.

RESULTS

Three AISI 4130 steel sleeves identified as sample 1, sample 2, and sample 3, and three AISI 4140 steel sleeves labeled sample 4, sample 5, and sample 6, were received from the contractor with nominal 2.54×10^{-3} cm (0.0001 in.) coatings of TiB_2. Cursory visual examination revealed matte finished coatings which were apparently uniformly deposited along bore surfaces. After erosion testing, bore surfaces exhibited areas that were polished, shiny, and mottled.

The erosion test data for AISI 4340 steel are presented in table 2, and the erosion test data for TiB_2 coated AISI 4130 and AISI 4140 steel are presented in tables 3 and 4, respectively. All bore surface losses are reported as volume losses as well as mass losses to facilitate erosion comparisons between steel and titanium diboride.

CONCLUSIONS

A comparison of the data reveals the following:

1. All samples display the same general trend in which erosion accelerates as pressures surpass 180 MPa (2600 psi).

2. Mass losses for TiB_2 (except for sample 3) are similar to mass losses for steel at all pressures. The sample 3 data are probably a result of massive spalling.

3. Volume losses for TiB_2 coatings are greater than volume losses for steel at all pressures. This indicates that either TiB_2 eroded more than steel or was subject to massive spalling or adverse steel interface reactions.

4. The standard deviations for coating losses are generally greater than those for steel. This suggests a uniform erosion process for steel and a non-uniform multi-phenomena erosion process for the coatings.

These observations suggest that the steel data reflect the intrinsic erosion resistance of steel, while the TiB_2 losses were caused by many effects and do not indicate the erosion resistance of TiB_2. Since the coatings were very thin, interfacial effects may have played a dominant role in the erosion. As a result, further testing with much thicker coatings is recommended.

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Table 1. M30 composition and physico-chemico properties

Composition (%)	
Nitrocellulose (12.6% N)	28.00
Nitroglycerine	22.50
Nitroguanidine	47.7
Ethyl-centralite	1.50
Graphite	0.1
Ethanol (residual)	0.30
Water (residual)	0.00
Properties*	
T_f (K)	2990
C_p J/mol-K	43.6
I (J/g)	1072
CO (mol/kg)	11.9
H_2 (mol/kg)	5.8
H_2O (mol/kg)	10.4
N_2 (mol/kg)	11.9
CO_2 (mol/kg)	3.0
Total (mol/kg)	43.1
M_w (g/g-mol)	22.3
HEX_{obs} cal/g	974

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* Calculated by Blake code.

Table 2. Erosion data for AISI 4340 steel

Charge weight (g)	Pressure (MPa)	Pressure (psi)	Burn time (sec)	Erosivity (mg/shot)	Erosivity (cm^3/shot X 10^4)
30	102 ± 2	14824 ± 246	17.6 ± .3	3 ± 1	4 ± 1
30	150 ± 1	21872 ± 169	10.6 ± .2	5 ± 1	7 ± 1
40	183 ± 1	26545 ± 203	8.5 ± .2	8 ± 2	11 ± 1
50	218 ± 1	31570 ± 113	7.4 ± .2	23 ± 2	30 ± 2
60	260 ± 2	37872 ± 322	6.9 ± .2	49 ± 2	62 ± 2

Table 3. Erosion data for TiB_2 coated AISI 4130 steel

Sample	Charge weight (g)	Pressure (MPa)	Pressure (psi)	Burn time (sec)	Erosivity (mg/shot)	Erosivity (cm^3/shot X 10^4)
1	30	149 ± 1	21852 ± 183	10.6 ± .2	5 ± 1	12 ± 2
2	30	150 ± 2	20782 ± 229	9.6 ± .3	6 ± 3	13 ± 7
	40	180 ± .5	26270 ± 69	8.5 ± .2	6 ± 2	13 ± 5
	50	217 ± 7	31611 ± 113	7.4 ± .1	19 ± 2	43 ± 5
3	30	146 ± 2	21427 ± 305	10.5 ± .2	12 ± 6	25 ± 10
	40	182 ± 2	26583 ± 321	8.5 ± .9	14 ± 2	31 ± 4
	50	217 ± 2	31577 ± 263	7.1 ± .3	29 ± 3	64 ± 7

Table 4. Erosion data TiB_2 coated AISI 4140 steel

Sample	Charge weight (g)	Pressure (MPa)	Pressure (psi)	Burn time (sec)	Erosivity (mg/shot)	Erosivity (cm^3/shot X 10^4)
4	30	150 ± 1	21933 ± 204	10.8 ± .2	6 ± 1	13 ± 3
5	30	142 ± 1	20703 ± 102	9.7 ± .3	5 ± 1	12 ± 2
	40	182 ± 1	26470 ± 148	8.2 ± .4	6 ± 4	13 ± 9
	50	217 ± 1	31662 ± 149	7.5 ± .2	18 ± 3	41 ± 5
6	30	148 ± 1	21547 ± 132	10.4 ± .2	6 ± 2	12 ± 5
	40	183 ± 1	26818 ± 202	9.0 ± .1	7 ± 3	15 ± 4
	50	221 ± 2	32210 ± 235	7.5 ± .2	22 ± 4	48 ± 10

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